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A Literature Review of Timber-Harvesting Effects on Stream Temperatures:

Research Needs for the Southwest

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Water temperature affects fish by changing their metabolic rate, changing oxygen content of water, influencing hatching and development time, and influencing migration. Creating a more open forest in the water-producing zone can change water temperature in shallow, low-volume streams. Research is needed on how timber harvesting affects water temperature to produce guidelines to meet Federal Water Pollution Control standards for cold-water fish.

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Projected increases in timber demands from Southwestern forests mean timber management must become more intensive. Precise estimates of amount of timber to be cut are probably not so important — in terms of influences on stream temperatures and fish populations — as how and where the timber is cut. The current trend is toward open stands which would allow more radiation to reach the forest floor.

Because of the location of timbered lands with respect to high precipitation and runoff, any change in structure of the forest will affect water quantity. Perhaps more important, however, is that it will affect water quality, especially temperature.

Over 2,000 miles of perennial streams could be affected by logging on National Forests in the Southwest:

Miles of Perennial Streams

Arizona		New Mexico	
Apache	242	Carson	425
Coconino	191	Cibola	33
Coronado	39	Gila	366
Kaibab	11	Lincoln	23
Prescott	59	Santa Fe	578
Sitgreaves	40		
Tonto	311		
	893		1425

Of this total, about 80 percent is a cold-water fishery resource in the spruce-fir and ponderosa pine zones. The importance of temperature to this limited cold-water fishery in a hot, dry climate needs to be considered in more detail.

Importance of Water Temperature to Fish

Water temperature is probably the most important factor affecting the physiology of fish. The range of temperature under which different fish live is very great, but for most species the

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comfort range is limited to a change of 12° to 15° F (Norman 1951). Since fish are poikilothermic they cannot regulate body temperature. In general, vital processes are accelerated by warm temperatures and decelerated by cold temperatures. Rapid cooling and warming can by lethal, especially to delicate cold-water species such as trout (Lagler et al. 1962). Acclimation to temperature can also be important. Chinook *(Oncorhynchus tschawytscha)* and coho salmon *(Oncorhynchus kisutch)* fry raised in 69° F water die when temperatures reach 75° F (Brett 1956). The optimum range for sockeye salmon *(Oncorhynchus nerka)* fry has been found to be 53° to 62° F (Donaldson and Foster 1940). Ideal water temperature for cold-water fish is between 50° and 65° F; generally they cannot tolerate temperatures over 75° F (Trippensee 1953). Warm-water fish are less specialized and can live in a wider temperature range.

Temperature affects fish by changing their metabolic rate, changing oxygen content of water, influencing hatching and development, and affecting migration. Metabolic rate rises with body temperature, which in turn determines nutritional requirements (Lagler et al. 1962). Brown (1957) found that brown trout *(Salmo trutta)* grew best between 45° and 48° F. Appetite was high at 50° F, as were maintenance requirements. Below 45° F the maintenance requirements were low but so was appetite. For most species the development time from fertilization to hatching decreases as temperature increases; in brook trout *(Salvelinus fontinalis)* it takes 165 days at 37° F but decreases to 32 days at 54° F (Hayes 1949). Pritchard (1944) found that high temperatures shorten and low temperatures lengthen the incubation period of pink salmon *(Oncorhynchus gorbuscha)* eggs.

Water temperature during the summer months has been cited as the most important limiting factor on the survival of trout (Needham 1938). Limiting temperatures for brook trout, brown trout, and rainbow trout *(Salmo gairdneri)* are 75°, 81°, and 83° F. This will vary with other factors, such as pH, oxygen, and carbon dioxide.

Temperature has also been found to influence fish distribution. Sockeye salmon come to the surface of a lake when temperature rises from 39° to 41° F (Foerster 1936). White (1939) reported that a salmon smolt descent from a brook in Nova Scotia was related to a rise in temperature. Vertical distribution of fish in lakes has been shown to be related to temperatures. Cisco *(Coregonus artedi)* migrate tc deep water in spring and spend the summer in the cool thermocline (Fry 1937). Trout in two lakes in Nova Scotia were found at a particular temperature rather than a specific depth (Hayes 1946).

The ability of water to hold oxygen increases as the temperature decreases. At 32° F water can hold 14.6 parts per million (p/m) of oxygen, but at 75° F can hold only 8.5 p/m at saturation (Welch 1948). Cold-water fish need a minimum of 4 to 5 p/m to survive over long periods.

Another consideration is the effect of temperature upon bacteria, algae, phytoplankton, and zooplankton. Organisms such as these usually follow van't Hoff's rule of increasing activity and production as temperature increases (Sawyer 1960). An increase in organisms will cause an increase in oxygen consumption, which lowers the amount available to fish. This is also true where organic material is decomposing.

Effects of Logging on Stream Temperature

Research on the effects of logging on water temperature generally has been limited to the Pacific Northwest and eastern United States. A literature review failed to find any results from research in the Southwest. To understand the importance of the results reported, it is necessary to review briefly the heat exchange process.

Change in water temperature depends on how much heat is received and the volume of water being heated. The energy producing the heat comes from solar radiation. Heat may be lost or gained by evaporation, condensation, conduction, or convection. These processes influence stream temperature only to a very limited extent as compared to direct radiation. Brown (1967) found solar radiation along forested streams was 0.3 to 0.4 langley per minute, but open stretches received 1.1 to 1.2 langleys per minute. Small streams with low summer flows and a large surface area in relation to volume react more quickly to microclimate changes than do large rivers. It is, then, the amount of sunlight that reaches the forest floor to warm the soil or directly heat the runoff from tributaries and main channels that changes the water temperature.

Studies in Oregon by Brown and Krygier (1967) show that clearcutting increased the daily stream temperature by 14° F in August, while an uncut watershed showed no stream temperature change in average monthly maximum. The streams studied were small, about 4 to 8 feet wide and 6 to 8 inches deep in summer. Summer water flows were less than 1 cubic foot per second. Such streams in Oregon are used for spawning and rearing by salmon.

Clearcutting on the Fernow Forest in West Virginia increased maximum stream temperatures in summer and decreased the winter minimum (Eschner and Larmoyeux 1963). The average maximum stream temperature increase on the clearcut area was 8° F, but temperatures over 75° F were observed several times. Eschner and Larmoyeux concluded that these temperatures over 75° F would probably eliminate brook trout in the stream.

In North Carolina, six forest cuttings were evaluated for effects on stream temperature (Swift and Messer 1971). All six showed an increase in summer maximums after cutting, with an increase of 1° to 12° F depending on type of cut. On one watershed, 8 years after the cut, stream temperature was 2° F less in the summer than the control. This decrease was attributed to dense shading effect from 8-year-old regrowth.

From research in the Douglas-fir region it appears that logging near the stream channel has the most effect in raising water temperature (Levno and Rothacher 1967). In Connecticut a survey revealed an increase of 10° F along a half-mile section where all brush was removed (Titcomb 1926).

Meeham et al. (1969) in Alaska studied the effects of clearcutting on salmon habitat. They noted a significant increase in average monthly stream temperatures. The maximum increase was 9° F during July and August. Green (1950) reported temperatures of a nonforested stream in the Southeast to be 13° F higher than an adjacent forested stream.

Stream temperatures increased significantly in two experimental watersheds in Oregon when floods removed the riparian vegetation in a partially cut watershed (Levno and Rothacher 1967). Mean monthly temperatures increased 7° to 12° F from April to August. Monthly maximum averages increased by 4° F in the second watershed after a clearcut.

The amount of stream temperature increase after any vegetation removal will depend on the amount removed and how it is distributed. Brown (1967), in studying energy budgets, found a decrease of 8° F when a stream passed through 700 feet of undisturbed canopy. Cormack (1949) and Green (1950) have shown the same relation in their work, principally that shaded streams are cooler.

These studies all indicate that removal of vegetation from a watershed will increase stream temperature. The increase can be either detrimental or beneficial, depending on which margin the stream is operating. For a stream that is cooler than optimum, a slight increase in temperature could increase productivity. In such cases logging would be beneficial. Streams with temperatures on the high side in July and August could become "trout-less" with an increase of only a few degrees.

In the Southwest where January surface temperatures are from 50° to 68° F and July surface temperatures are from 68° to 86° F, logging along streambanks and heavy cutting within a watershed could be detrimental to trout in shallow, low-volume streams. Although there is no evidence from either Arizona or New Mexico, research from the Northwest and East adequately demonstrated the relationship. However, results are all from areas with a much cooler climate than the Southwest. If clearcutting in a cool region such as Oregon raises the daily water temperature by 14° F, what would the effect be in a warmer climate?

The only way to protect trout environment in timber harvest areas is to maintain a vegetative cover along the streambanks. The amount to leave is not a precise figure and will depend on topographic shading, height of streamside vegetation, and width and volume of the stream. Cormack (1949) recommended cover strips of 60 to 100 feet along both banks to keep temperature down and to preserve esthetic values.

The effect of clearcutting on stream temperature can be predicted by using a technique developed by Brown (1970). In areas where clearcutting is being considered, knowing the approximate temperature changes resulting from the cut will provide the evidence needed to maintain a residual strip adjacent to the stream.

Research Needs

Research on the effects of logging on stream temperature should be a high priority in Arizona and New Mexico. Data are needed so that streams in harvested forests will meet standards set by the Federal Water Pollution Control Administration for optimum temperatures for coldwater fish (USDI 1970). These standards are:

Resident trout waters: winter, 42° to 58° F;
summer, 42° to 68° F.
Spawning areas: resident and anadromous, 45° to 55° F.
Rearing areas: resident and anadromous, 50° to 60° F.

Research should include the following:

1. Identification of perennial streams with temperatures that are marginal on the high side in prospective areas of timber harvest.
2. Studies on the effect of timber harvesting on water temperature in the ponderosa

pine, mixed conifer, and spruce-fir zones to include different intensities of cut as well as different cutting patterns.

3. Determination of temperature ranges of rare and endangered fish that exist in the Southwest.

4. Studies to determine the importance of riparian vegetation in maintenance of the aquatic habitat.

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